Development of a Radar/SAR Assimilation System for Internal Wave Prediction

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LONG-TERM GOALS

Oceanic internal waves, particularly large non-linear ones, can have a significant impact on ship and submarine operations when they move through a region due to the surface currents and buoyancy issues such waves induce. Thus the Navy has a need for a predictive system that can tell a ship or submarine what the future internal wave effects will be in their region.

The long term-goal of this project is to provide a component of such a predictive system that will take remote sensing imagery of a region and estimate the current internal wave characteristics within that region. It is then anticipated that these internal wave characteristics will be handed-off to an internal wave propagation model that will generate the future characteristics of the internal waves.

OBJECTIVES

This program will focus on utilizing synthetic aperture radar (SAR) or real-aperture radar (RAR) imagery to characterize internal waves. A SAR or RAR system will only image surface effects on the ocean (such microwave sensors do not penetrate into ocean any significant depth), so internal wave characteristic will be derived from their surface manifestations. The most significant surface effect will be a modulation of the surface current due to the passage of the internal wave. Thus the program will focus on estimating surface currents from radar cross section imagery (from either SAR or RAR systems) and using those to estimate internal wave characteristics. The program has four objectives.

(1) ***Inversion of radar cross section signatures to surface current gradients and internal wave characteristics.*** This is the development of a tool to take the radar cross section image and generate estimates of surface current gradients

(2) ***Automated internal wave detection.*** This will develop a tool to automatically locate internal wave signatures in radar cross section imagery and estimate their propagation characteristics from multiple imagery.

(3) ***Development of the end-to-end system***. The two components developed above will be put together into a single, automated, system and validated at a sponsor-determine location *with in situ* observations of the internal waves for comparison.

(4) ***Documentation.*** The final objective will be to provide documentation for the final system and its validation.

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APPROACH

(1) Inversion of radar cross section signatures to surface current gradients and internal wave characteristics.

The initial effort will be to compare the existing models in the literature that have successfully reproduced X-band results using various modulation mechanisms and derive a general form for the forward model that includes a parametric approach to the small-scale modulations along the large-scale waves as well as a parametric form for the relaxation rate function. We will not be concerned with attaching a physical source to these parameters, rather we will try and derive a general form that can encompass each of the approaches depending on the values of the parameters. We will then compare this forward model to existing validation data sets to determine whether values for the parameters could be set to constants, or whether they need to vary significantly from data set to data set. This will be a combination of historical data (we anticipate using at least published results from the SARSEX experiment over the Mid-Alantic Bight, the HI-RES experiment over the Gulf Stream edge, and validation data sets included in the European MARSAIS project), new data collected in the Luzon Strait region during the first year of the NLIWI, and new data collected in the second year over the Mid-Atlantic Bight. We also will perform a sensitivity study on the forward model parameter values to determine how accurately we need to estimate them in order to generate stable RCS predictions.

The next effort will be to build the inversion scheme to estimate surface currents and model parameters from RCS signatures. We anticipate that this will be an iterative approach, where we start with initial guesses for the current gradients and model parameters, and then successively improve them until the simulated RCS signatures from the forward model matches the observed RCS signature. The key to such a scheme is the estimation of the gradient of the error (where the error is between the simulated and actual RCS observations) with respect to the parameters being estimated (i.e. current gradient field and model parameters). We will investigate a number of ways to generate this error gradient. One will be to assume a functional form for the surface currents induced by the internal wave, then numerically calculate the error gradient via small perturbations of the parameters for the surface current function as well as the forward model. This will be effective as long as the number of parameters is small. We will also investigate removing the need for a functional form of the current, and directly estimate the two-dimensional current gradient field. This will require estimating the error gradient via the inversion of the forward model, since the number of parameters will be too large for numerical techniques. The model inversion will be performed via adjoint techniques, for which the models are run backwards with errors as “inputs” and thus gradients as “outputs” to the adjoint or inverse model.

In addition, we will examine exploitation of the surface wave signatures to determine surface current maps. High resolution (3-6m) satellite SAR imagery could be available that could provide some amount of dwell time over the scene, thus allowing the estimate of wave motion in addition to wave length. This would generate both period and wave number, which could then be inverted to derive the surface current that the wave is feeling (assuming that the wave is not feeling the bottom). If the dwell time is not sufficient to estimate wave period, we will also investigate the use of the so-called wave ray equations, that determine changes in wave length and direction as a wave propagates over the current field, to invert the observed changes in the wave field into surface currents. Note that this approach assumes that the “same” wave field exists throughout the image.

(2) Automated internal wave detection

Some work in this area has been going on in Europe under the Marine SAR Analyses and Interpretation System (MARSAIS) program using wavelet analysis. Under our existing NOAA/NESDIS programs we have been collaborating with the MARSAIS staff on wind and ship algorithms; we anticipate continuing this collaboration to include internal wave algorithms. We will first determine what the state of the art is in the MARSAIS project, and then use this as a base for our development. The biggest problem for an operational system will be the rejection of false alarms; something that the MARSAIS project has not focused on. We anticipate that this will require spatially locating proposed internal wave packets on a map, and then utilizing their relative relationship with each other (i.e. true internal wave packets will be along some line with some generally known spacing) as well as their relationship to the coastline (i.e. true internal waves will propagate in known areas and directions). This will help eliminate errant signatures from surfactants or wind rows that may locally have similar characteristics to internal wave signatures, but globally are not in the appropriate locations.

Under this task we will also address the multiple image problem. That is, how to determine the same internal wave packet in two images of the same location taken at different times. We will derive metrics to characterize the internal wave packets from each image (number of waves, length, curvature, strength, etc.) as well as specify their spatial location. We will then perform the "matching" algorithm on the packet characterizations to find matches that are consistent with known internal wave propagation. This will generate a master list of time-series properties from a given internal wave packet.

The final step in this task will be to take the master list of internal wave packet properties and derive local oceanic environmental conditions. This part of the system will allow the user to specify sets of assumptions (i.e. a two-layer model, constant depth of the upper layer, known bathymetry, etc.) and will then derive the oceanic conditions consistent with the internal wave packet characterizations and these assumptions. We will utilize the same techniques as have been discussed in the literature; thus this step will be dominantly an implementation of known techniques.

(3) Development of the end-to-end system.

The task will combine the two previously developed tools and put them together into a single, automated, tool. This approach will be straightforward connection of the two tools. Then the system will be validated on some sponsor-determined location.

(4) Documentation

Documentation for the tool and the validation process will be generated

WORK COMPLETED

Over the last year we have received all of the SAR remote sensing data from the FY '05 South China Sea (SCS) experiment and have built the tools required to be able to read and manipulate the imagery. We have received the surface current ground truth collected by the APL plane; coordinate for the other ground truth taken during SCS 05 is currently ongoing.

To start the assimilation task, we required a forward model that would solve the wave action balance equation to determine the change of wave characteristics (amplitude, wave length, wave direction) as the surface waves interact with surface currents (and in particular the current induced by the internal waves). General Dynamics (when it was ERIM) has developed such a forward model in the late 80's that was known as the ERIM Ocean Model (EOM) and had been accepted as a standard back then for model development. We decided to use this model as the starting point. We had to collect all of the code and make sure that we could run the forward model. This has been completed, and in fact General Dynamics has officially agreed to release it as Open Source code, so it can become the framework for a range of possible model development. There has also been some discussion among the contractors on this program about setting up standards for models run so that we can directly compare results, and we have got EOM running on this standard input set. We now need to use EOM to derive the inverse model (i.e. the assimilation using RCS modulations) and to incorporate some of the newer forward model aspects.

We have also looked at examining the wave characteristics to determine surface currents. There were some high resolution (12.5m samples spacing) SAR imagery collected during the SCS '06 experiment and we have started to look at the relationship between wave characteristics and mean RCS modulations. Since we know that the RCS modulations are due (either directly or indirectly) to surface current effects, correlation of changes in wave characteristics (amplitude and/or wave length) with average RCS modulations would indicate that the wave are also being effected by the surface currents. We have just started this process, but to date we show a very good correlation between RCS modulations and scaled wave amplitude. Since wave amplitude changes can be directly related to the surface currents that the wave feels, this shows great promise for estimate currents directly.

RESULTS

Figure 1 shows an example high resolution SAR image taken from the SCS'06 experiment, which has been flattened and re-scaled to show the internal wave signatures more clearly. The red line in Figure 1 shows a cut through the RCS modulations that are plotted in Figure 2. Note that both large-scale modulations (on the order of 2-3 km in wavelength) are evident along with modulations on much smaller scales (~60-80m). The large scale modulations are due to changes in the mean RCS from the surface currents induced by the internal waves. These are what all the forward models are predicting and what we are working toward inverting via an assimilation code. The smaller scale modulations are modulations in the RCS caused by surface ocean waves. We have implement code to take short Fourier Transforms along these curves to estimate the peak wave number and wave amplitude as a function of the average RCS modulations (and thus as a function of where we are with respect to the internal wave surface current). Figure 3 shows one such relationship, where the average RCS value (averaged over 800m) is plotted as a spatial plot along with the peak Fourier amplitude (scaled to fit on the plot) for FFTS taken over the same 800m region. We limit the Fourier analysis to only consider surface waves with wavelengths from 50 to 200m. Note that very high correlation between the two, which indicates that we may be able to use changes in wave amplitude to estimate the surface current that is causing the RCS modulations. This would be easier than inverting the RCS models.

IMPACT/APPLICATIONS

If successful, the resulting system will be one component of an operational Navy tool to allow prediction of future internal wave activity in a region so that the Navy vessels can maneuver appropriately.

RELATED PROJECTS

There are no ongoing related projects that are closely identified with this project.

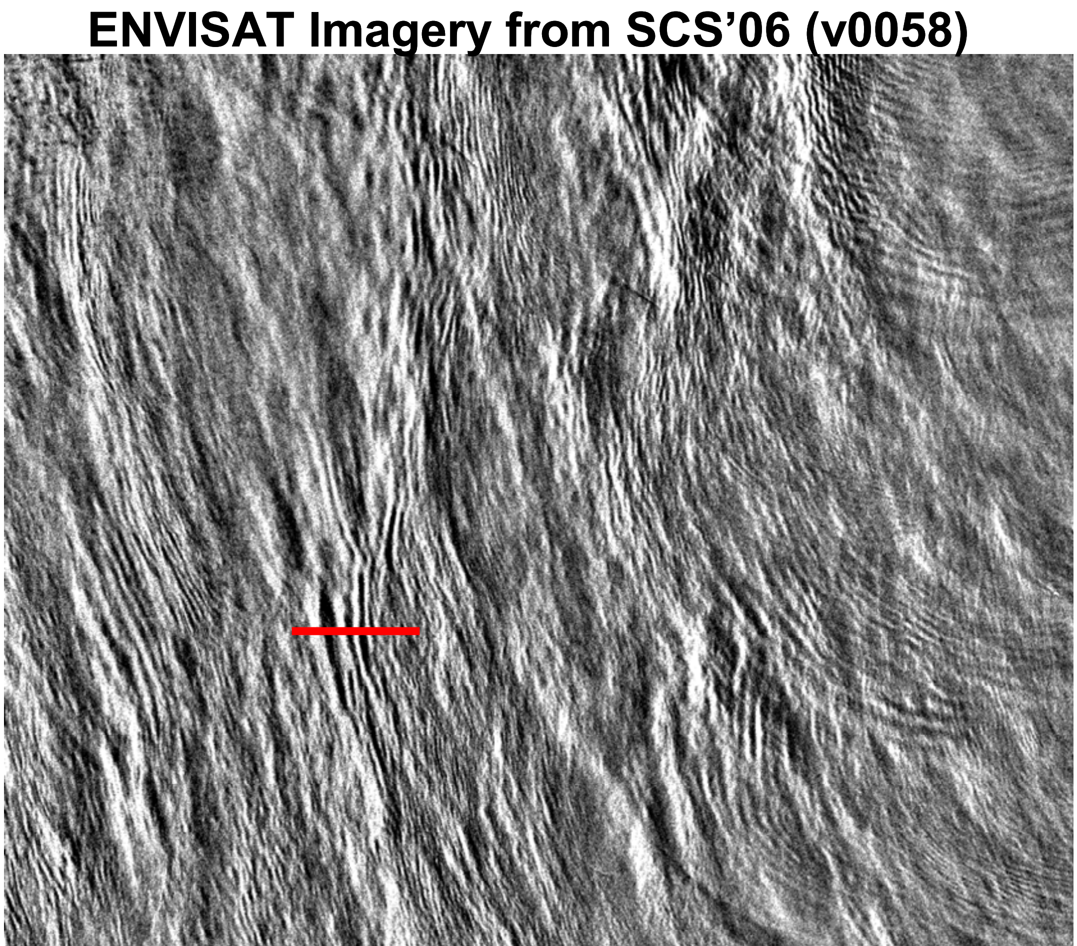

Figure 1 : Example high resolution (12.5m) image taken by the ENVISAT SAR satellite over the region of the SCS'06 experiment. The features that can be seen are from internal waves. The red line shows the region where plots were derived below.

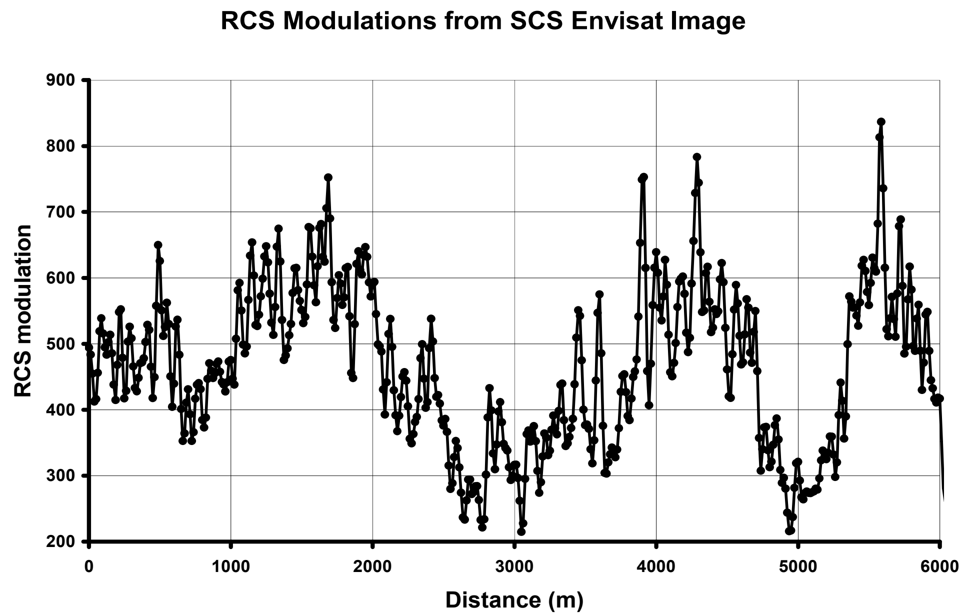

Figure 2: Cut of the RCS modulations along the red line in Figure 1. Note the two scales of modulations; long scales (~3km) that are changes in the mean RCS caused by interactions with the surface currents induced by the internal wave, and shore scales (~50-100m) that are caused by the modulations of the surface waves.

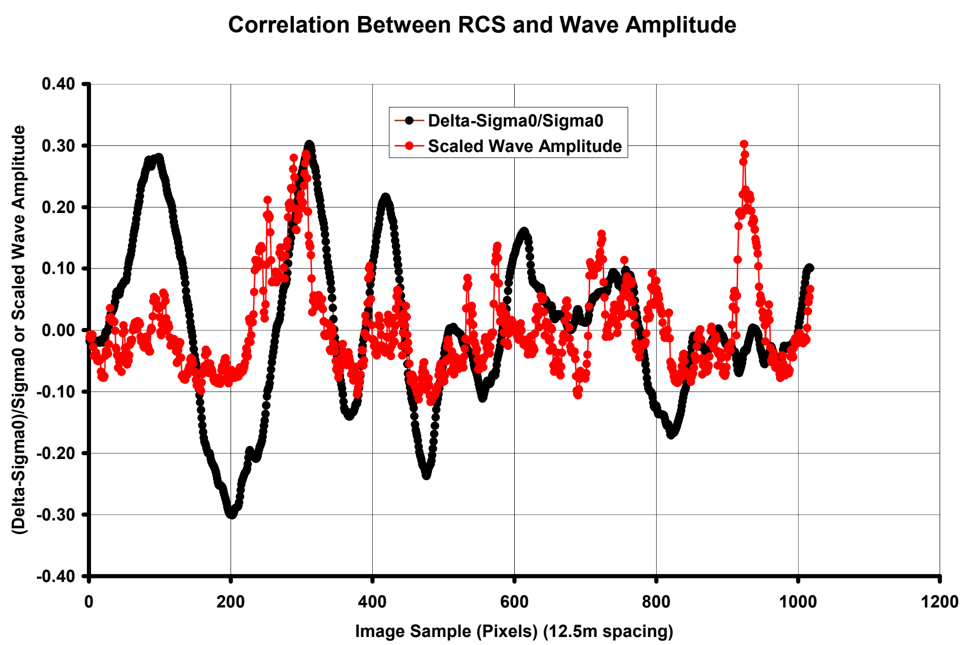

Figure 3: Plots of the average RCS (averaged over 800m) from the data in Figure 2, and the peak Fourier amplitude calculated over the same 800m region (but limited to waves with wavelengths from 50 to 200m). Note the strong correlation between changes in the mean RCS (which are caused by interactions with the surface currents) and relative changes in the wave amplitudes. This is an example of results that indicate that we might be able to estimate surface currents from wave characteristics imaged by these high resolution SAR systems rather then invert the RCS models.